DOE/FETC-991099

Natural Gas Supply and Utilization for the 21st Century

Understanding Technology Needs In Emerging Gas Markets

July 1999

Prepared by

ENERGETICS

For the

U.S. Department of Energy
Office of Fossil Energy

and the

Federal Energy Technology Center

DOE/FETC-991099

Natural Gas Supply and Utilization for the 21st Century

Understanding Technology Needs In Emerging Gas Markets

July 1999

Prepared by

Jack Eisenhauer
Keith Jamison
Ross Brindle

Energetics, Incorporated

For the
U.S. Department of Energy
Office of Fossil Energy

and the
Federal Energy Technology Center

Table of Contents

Acknowledgments

This report summarizes the views and insights of over 70 experts within the natural gas community that was obtained from two workshops and subsequent reviews. Recognition and appreciation is extended to the 48 workshop participants who volunteered their personal time to contribute their valuable expertise and perspectives. Although the workshops were sponsored by the U.S. Department of Energy (DOE), the information presented in this report reflects the views of the industry participants and not the DOE.

The overall project was initiated through the Office of Fossil Energy Natural Gas Coordinating Committee by Ralph Carabetta, Deputy Director, Federal Energy Technology Center (FETC) and Sandra Waisley, Associate Deputy Assistant Secretary, Natural Gas & Petroleum Technology, Office of Fossil Energy (FE). The effort was coordinated and managed by Leonard Graham (FETC), Peter Cover (FE), and Ms. Waisley. Valuable advice and reviews were provided by Rita Bajura, Abbie Layne, Mark Williams, Charles Komar, and Venkat Venkataraman, all of FETC.

Executive Summary

The natural gas industry is in the midst of unprecedented change. Traditionally regulated energy markets are being transformed into competitive ones, facilitated by changing regulations and new technology. Lessons from the telecommunications and airline industries have shown that deregulation changes the dynamics of markets and business decisions. It forces the industry to restructure, creating opportunities for new products and services and attracting new business enterprises. The ultimate goal of gas market restructuring is to increase economic efficiency and provide the consumer with more choices in selecting energy services that provide value.

How will the new competitive environment for energy services change the structure of the natural gas industry and how will this change affect the magnitude and direction of gas R&D investments? As business strategies replace the public service objectives of gas companies, it is prudent to assess possible shifts in technology investments and research priorities within the gas industry. At the core of this issue are the appropriate roles of industry and government in supporting gas research.

The U.S. Department of Energy Office of Fossil Energy and the Federal Energy Technology Center endeavored to take a fresh look at the structure and direction of federally funded gas research by considering the goals and plans of gas companies and their extended industry. The Department sponsored two industry meetings in January and February 1999 to examine the forces of change within energy markets and the key technological challenges facing the expanding growth of natural gas. This unique, industry-based perspective, summarized in this report, will help shape the direction of future DOE gas programs.

The first meeting brought together a unique cross-section of 16 gas, electric, and energy executives to discuss the most critical market, business, regulatory, and technology issues affecting future gas supply and demand. The second meeting included 32 experienced technology and research managers from the energy industry who collectively outlined a research agenda for addressing these issues and recommended R&D priorities for public sector action. The result is a strategic portfolio for public-private partnership that will enable the gas industry to meet the growing demands and expectations of consumers and provide affordable, clean, reliable, and safe energy for the nation.

The findings of the industry meetings represent valuable insights into the issues and responses for the natural gas industry.

Industry Outlook

- The integrity of the gas delivery and storage infrastructure will be critically important in meeting future demands
- Gas and electric industries will converge, possibly with the telecommunications industry, to take advantage of synergies and efficiencies
- Distributed generation will change patterns of energy supply and use and will require new enabling technology to ensure reliable, low-cost power systems and networks
- More predictability in regulatory policy is needed to help stabilize business strategies and encourage technology investment
- Government funding of “public benefit” R&D will become more critical as private firms lose incentives for long-term, public service R&D

Selected Public Sector R&D Priorities

Exploration and Production

- Novel drilling and casing methods
- Technology that sees ahead of the drill for polycrystalline diamond compact (PDC) drills and horizontal wells
- Improved down hole tools and technologies to increase seismic resolution

Transmission

- National model for transmission pipeline system
- Diagnostic system and neural network to capture and use information
- New inspection devices for pipeline integrity, safety, and environmental protection

Fuel Conversion and Processing

- Low cost methane-to-hydrogen convertor

Power Systems

- Inexpensive, solid-state interconnect device and parameters for standard interconnect design to enable distributed generation
- Lower-cost materials and manufacturing methods for power systems
- Low-temperature catalysts for emissions control
- Inexpensive sensors for emissions monitoring
- Natural gas injection for preheated coal-fired power systems
- CO_2 separation and sequestration technology (also applies to end user)

End-Use

- Fuel cells for vehicles and residential use

Key Technology Themes

Several reoccurring technology themes were identified by industry as critical for promoting a strong natural gas industry.

- Advanced gas storage technologies for large- and small-scale applications
- Gas-to-liquids conversion technologies
- Durable, safe, and sophisticated pipeline networks
- Distributed generation technologies and supporting systems
- Integrated information and telecommunication systems to optimize gas distribution and transactions

The findings of these two industry meetings represent the insights of a relatively small but knowledgeable cross-section of the gas and energy industry and are by no means exhaustive. A more comprehensive effort may be desirable to reflect a broader range of gas industry opportunities and technology needs. The results do, however, provide a framework for recognizing both the challenges of the future and the need for the public and private sectors to work together to address these challenges.

1 Key Trends and Drivers

The trends and drivers that will shape the future of natural gas are unusually complex. As the natural gas industry restructures, the traditional industry segments – producers, pipeline companies, local distribution companies, and equipment suppliers – will likely realign to take advantage of new market and profit opportunities. Projected growth in gas use by power producers is complicated by restructuring that is occurring within the electric industry. Furthermore, increasing pressure to improve air quality and reduce greenhouse gas emissions has created new opportunities for using natural gas as a solution or transition fuel. Finally, if projections for gas are accurate, the physical infrastructure may be insufficient to accommodate the industry's growth.

The key trends and drivers affecting the natural gas industry include markets and customers, climate change, environment, technology, regulations and public policy, electric utility trends, and gas industry restructuring. Each of these is summarized below.

Markets and Customers

U.S. natural gas production and consumption are expected to increase in the next 10 to 20 years, while prices are expected to remain low. Demand estimates range from 29 to 33 tcf/year by 2015 under a business-as-usual scenario, compared to 22 tcf/year in 1997. However, if the Kyoto Protocol were implemented, gas demand would be greater – as much as 35 tcf.

Fuel price will be the primary determinant of future natural gas production and use. Decisions by producers to expand production or by consumers to shift to other fuel sources will primarily be based on their response to prices.

- ***Greater price volatility during transition.*** During the transition from regulated to competitive energy markets, gas prices will become more volatile as a result of periods of excess supply or demand, which may be localized or national.

- ***Price stability after transition.*** Competition and market efficiency are making fuel prices transparent to customers and producers. Fuel prices will stabilize as the natural gas infrastructure becomes more efficient in managing demand and supply imbalances and as consumers gain better access to price information.

Substantial growth in natural gas use by power producers is expected. Gas demand by electric utilities and non-utility generators could double or triple in the next 20 years (see Electric Utility Trends). However, there is much uncertainty about the rate of growth and the degree of competition from other fuels.

Globalization of market economies and energy services will reshape natural gas production and use within the United States. Increased interdependency of market economies worldwide will affect domestic natural gas production and use. In addition, energy companies will increasingly look for investment opportunities in natural gas industries in other countries.

- ***Prevailing economic conditions, both here and abroad, will drive demand for natural gas and other energy sources.*** The strength of global economies will greatly influence the demand for natural gas and the health of the industry. The recent economic crises in Asia and Brazil may cause natural gas markets to grow more slowly than previously projected. Any failures in emerging market economies could have a significant impact on energy security and the health of the energy industries.

- *Globalization of energy services will increase imports and exports of natural gas.* Imports from Canada will continue to increase, while trade with Mexico is less certain. Mexico may become an opportunity for additional production despite the limited infrastructure and some projections indicate the United States will continue to export gas to Mexico. Energy companies will become increasingly international not only in production but also in delivery and utilization.

The changing composition of the U.S. economic sectors will create new customer needs and alter traditional patterns of energy use. Changes in demographics, personal wealth, life styles, and industrial base will transition energy demand from traditional needs to emerging ones. Increased use of natural gas will be partly dependent on the ability of the industry to recognize new opportunities and offer services that respond to customer needs.

- *Changing population patterns will alter residential and transportation energy demand.* Population trends in the United States, such as increases in median age, immigration, family income, and urbanization, will alter demand for natural gas. For example, the mix and turnover rate of the housing stock combined with regional growth patterns could increase the energy use of homes and shift gas demand to new regions. Additionally, the trend for more Americans to use information technologies to work from home will change transportation patterns.

- *Emerging commercial practices, such as the growth of the Internet, will change energy use.* Retail and commercial sales through the Internet have been increasing dramatically. Continued growth in electronic commerce is expected to substantially increase electricity use and change transportation energy use patterns. As much as 13 percent of current electricity use can be traced to the digital-Internet economy and it this could jump to nearly half within the next decade. In transportation, a possible decrease in energy for local travel may be coupled with an increase in energy for air and freight deliveries.

- *The underlying performance of traditional and emerging industries will shape demand growth.* The growth of information-based industries and the potential stabilization or decline of traditional manufacturing industries will change both overall energy demand and the fuel mix within industry. Some industries, such as semiconductor plants, have the same energy density as other major manufacturing plants.

Customer willingness to adopt new technology will determine demand trends. The speed with which customers accept and adopt new technologies will greatly affect gas demand. Gas industry changes will tend to shape expectations and drive customer needs.

Climate Change

Concerns about climate change will increase attention on greenhouse gas emissions from fossil fuel combustion. Despite continuing research to fully understand climate effects, pressure will grow to reduce greenhouse gas emissions associated with energy production and use.

Implementation of the Kyoto Protocol would have a huge impact on energy production and use. Although it will be very challenging, tremendous pressure will be placed upon electric utilities and industries to reduce greenhouse gas emissions and meet the current requirements of the Kyoto Protocol.

- *Natural gas will serve as an ideal "transition" fuel.* Under most reduction scenarios, natural gas use would expand greatly in the near term as an alternative to coal and petroleum-based power generation. Natural gas emits less CO_2 per Btu than coal or oil and can be substituted in power plants without extensive capital investments. Natural gas-fired, combined-cycle power generation is also more efficient than conventional fossil-based power production.

- *Flaring and release of uncombusted methane worldwide will become critical concerns of natural gas production.* Reduction in the emissions of these two sources of greenhouse gases will become a major issue for natural gas production.

- *Voluntary adoption of advanced technology offers an alternative to regulation.* The ability of industry and utilities to develop and implement advanced technologies may determine whether mandatory regulations or carbon taxes will be necessary to implement Kyoto provisions.

Recent weather conditions suggest more erratic climate patterns. Extreme summer and winter weather resulting from El Niño and La Niña have created atypical power demands and more electric outages. Continued erratic weather patterns could result in additional outages and customer concern over power reliability.

Environment

Increased pressure to reduce combustion-related air emissions will significantly influence fuel choices and power generation decisions within utilities and industry. This will likely create opportunities for natural gas because of its low emissions compared to other fossil fuels.

Environmental policy is becoming energy policy. Due to continued low fuel prices, future energy policy will be shaped by environmental policy objectives. Continued long-term economic expansion will place additional emphasis on environmental and energy issues. Energy developers and consumers are increasingly concerned about the unpredictability of environmental regulations and policies.

Environmental restrictions will increase for supply development. Energy development will be subject to additional restrictions that could limit access to new and existing sources of natural gas.

Technology

New technologies, including those outside the natural gas industry, could have a major impact on natural gas services, prices, and markets. Competition will attract new ideas and novel applications of existing technologies.

New technology could accelerate market for distributed power. Advances in microturbines, fuel cells, reciprocating engines, and smart control systems could greatly increase the viability of distributed power generation for end-use power customers.

Information technologies and microelectronics will significantly transform the natural gas industry. Friendlier, quicker information and computer technology will continue to migrate into the natural gas industry, creating new opportunities to improve operations and increase the value of gas for consumers.

- *Real-time purchasing and pricing through the Internet.* The Internet, electronic bulletin boards, and other telecommunication technologies will facilitate price transparency and instantaneous access to supplies and markets.

- *Smart control technologies will be critical to all aspects of the energy business.* An explosion of smart sensing and control technology will allow companies to manage energy more effectively. It could also enable electric utilities to remotely control customer power equipment to better manage power system loads.

Gas cooling offers potentially large opportunity for summer gas sales. Cost-effective gas air conditioning for the home would create a new, large market for gas during summer months.

Cost-effective technologies to find and develop gas will be needed in order to increase supply. The expansion of gas supply in an environment of low wellhead prices will require that new exploration and production technology be highly cost-effective.

Regulations and Public Policy

Some regulations reflect old ideas about technologies and markets and may act as impediments to new market interactions. The perceived piecemeal approach to environmental regulations creates uncertainty that inhibits private investment in new technologies and delays construction projects. Incentives for "public service" R&D have all but disappeared, requiring a greater role for government.

Siting gas pipelines will become increasingly difficult. It will become increasingly difficult to install long "green field" pipelines due to environmental regulations and land owner issues, including access to federal lands. These difficulties will greatly increase both the lead times and costs required for new pipeline construction.

Tax issues could hurt profitability of electric generating stations. Some communities want power plants in their areas for the tax revenue but want to tax them to the point where they begin to become unprofitable.

Support for "public service" R&D is disappearing. Energy deregulation and increased price competition has resulted in less R&D investment available for long-term and "public" technologies. Energy security remains an important national issue, but there are no market incentives to support it.

Electric Utility Trends

Restructuring of the electric utility industry is creating new markets but will also create a messy situation in the near term, punctuated by periods of over supply and severe price fluctuations. Market uncertainty will shift investment to low-risk generation that will generally favor gas.

Large growth in gas demand by electric utilities. The electric market represents the largest growth area for gas. This positions the electric industry as both a key customer and a key competitor. Restructuring will increase the number of merchant plants and stimulate additional gas sales.

- *Increased peaking needs affect the gas delivery infrastructure*. Most natural gas pipelines do not serve a peaking unit well. An increase in merchant plants and utility peaking units will create new challenges for natural gas distribution.

Capital effectiveness of new plants will be critical. Investments in new power stations will emphasize low capital-cost units that are flexible to meet changing demand requirements. Small- and medium-sized gas-fired plants that are clean and highly efficient will be used to meet intermediate and peak loads and will be greatly favored over new coal- or oil-based baseload capacity, at least for the next decade.

Plant life extension for nuclear and coal. Utility demand for natural gas will be tempered by low-cost strategies associated with coal and nuclear production. Plant life extensions will make coal and nuclear power viable low-cost alternatives to new gas-fired power generation.

Demand for distributed power will increase, driven by the need for greater mobility, energy reliability, and protection against price peaks. Consumers requirements for greater mobility will increase demand for portable equipment and power supplies. Recent increases in weather-related power outages have heightened interest in household power systems. Consumers may also view distributed power as a strategy for avoiding peak pricing. Utilities will struggle as they figure out how to make distributed generation a profitable part of their business.

Gas Industry Restructuring

Restructuring within the natural gas industry is leading companies into new business and markets. However, there is considerable uncertainty over the direction of these markets that makes it difficult for companies to develop effective corporate strategies.

New business structures emerge in the gas industry. Traditional gas business areas – exploration and production, transport, distribution, and use – are becoming realigned as companies attempt to expand their core competencies and protect or build their market position. Additional consolidations are expected within the industry as competition increases. New organizational structures will emerge that will include vertical integration, horizontal integration, and virtual organizations.

Financial expectations will influence investment decisions. Deregulated gas markets will force companies to place financial considerations above all others in making new investments.

- ***Large market capitalization needed.*** Significant new capital will be required to support the infrastructure growth to accommodate a 30 tcf/year demand future. However, with today's low gas prices it is uncertain whether adequate financing will be available. Price stability will be important for capitalization.

- ***Shareholder expectations will increase.*** Shareholders and financial markets will expect profits from natural gas companies that will shape their investment decisions. The time horizon needed to show performance results will be greatly compressed.

Discrepancy between areas of production and use during transition. The physical distance between production and use is growing. The biggest market for new electric power is in the Northeast but pipelines are not being built there because utilities do not want to sign up for long-term contracts.

Critical need for long-term, "public" R&D investment. In a competitive environment, R&D projects must result in a clear competitive advantage for the company. Energy service industries are entering many new markets and businesses, creating a lack of focus for R&D investment. As the industry realigns itself, gaps in R&D will emerge that must be addressed by government and industry.

2 Implications: Opportunities, Barriers, and Needs

Most companies within the natural gas industry are vigorously developing and pursuing business strategies that will position them for growth and profitability in newly competitive energy markets. The high degree of uncertainty concerning the future needs of customers and the eventual structure of energy markets is resulting in a wide variety of responses. Companies are reevaluating criteria for new technology investments and determining research needs. Policy makers are determining which incentives are appropriate to maintain social and public benefit objectives in a competitive environment. Customers are beginning to consider new energy purchase options that create a variety of choices for different levels of service and price. As trends emerge, these stakeholders will reassess and adjust their positions in order to maximize benefits.

The major implications resulting from the preceding trends and drivers can be grouped into markets and prices, business strategies, infrastructure, technology, and policy.

Market and Prices

The economic efficiency created by competitive markets will resolve imbalances in demand and prices and lead to the convergence of gas and electric services. During the transition from regulated to competitive markets there will not be a good match between price discovery and value relative to the customer. However, economic efficiency will lead to price and commodity convergence within the energy industry.

- ***Customers will purchase energy attributes rather than specific fuels.*** Fuel choices will be based on financial considerations since customers will focus on energy services and the value they provide. Recognizing this, companies will restructure to attain greater flexibility in meeting customer needs.

- ***Real-time pricing, metering, and control will lead to price convergence.*** Technology will enable energy prices to move closer to the value of the service being provided on an hourly or minute by minute basis.

Electric utilities will be viewed as both a customer, a competitor, or a partner depending on the specific markets being served. The growth of gas in electric markets will make power generators an important customer and will lead to cooperation in some markets. However, electric generators and gas suppliers will still compete fiercely in other markets.

Industrial trends will reshape gas demand. As demand grows in the electric sector, new concerns will arise surrounding the needs of industrial customers and their effect on demand and prices.

- ***Near-term stagnation of major industrial customers will hurt gas prices.*** As U.S. manufacturers face new competitive pressures resulting from sagging Asian and South American economies, they will look to gas suppliers to help them further reduce energy costs.

- ***Industrial ecology will emerge as a strategy to better integrate manufacturing functions among fuels.*** Businesses will take fuller advantage of opportunities to use waste heat and materials to improve productivity and reduce wastes.

Business Strategies

Competition will likely result in more mergers, consolidations, and acquisitions within the gas industry. The uncertainty created by deregulated markets will stimulate new corporate alignments in order to manage risk, lower unit costs, and gain access to markets and assets. This will cause many companies to diversify their businesses. To survive, small companies may seek new alliances to compete against larger companies. Mergers and consolidation may require that PUHCA be revisited.

- ***Winners will rebundle services for customer convenience.*** Commodity price may prove less critical for successful energy products and services. Successful companies will recognize the need for customer convenience and service and offer customers innovative packages that could include gas, electric, cable, telephone, and Internet services at attractive prices.

- ***Flexibility will be key to successful business strategies.*** Uncertainty over fuel price, customer needs, and regulations will drive businesses to develop multiple energy options that are offered seamlessly to customers.

The convergence of the electric and gas industries may result in the emergence of 15 to 20 full-service energy providers. Size will become an important factor in new markets. The industry will likely see new entrants such as oil companies that will exploit their size and capital structure to dominate energy markets.

- ***Large companies will help shape policy.*** The major companies will work with state regulators to help shape restructuring policies. Different approaches to restructuring will create different opportunities for profit in various states.

- ***Companies will look for synergies across their value chain.*** In offering a full range of services, integrated energy companies will seek opportunities to develop creative services and technologies that add value for customers.

International markets will create new opportunities for energy service providers. As energy companies expand into foreign markets, it will create opportunities to deploy beneficial technology throughout the markets they serve. Businesses will look to take advantage of internal trading of CO_2 credits within their company.

Private funds for new gas research and development will continue to be tight. Businesses will become more risk-adverse in their technology investments. This will translate into less money available for R&D and the requirement for shorter payback periods.

Infrastructure

The integrity and efficiency of the gas delivery infrastructure will be critical for gas growth. The integrity of the gas infrastructure may be the most critical barrier to achieving a 30 tcf/year economy given the age of existing pipelines and the lead times required for new construction. Financing for new capital projects will be driven by price signals, but there may be a significant lag that could create transmission bottlenecks and stranded assets.

- ***More efficient use of existing pipelines will solve some problems.*** Technologies that enable greater pipeline throughput and more efficient allocation of resources to areas of greatest value may help to avoid a potential crisis in the gas infrastructure.

- ***Gas storage will become more critical.*** Better use of regional and seasonal storage strategies will help mitigate temporary imbalances between supply and demand. Gas storage creates a distinctive competitive advantage for gas over electricity as an energy commodity.

Infrastructure constraints may stimulate innovative solutions. Pipeline constraints could lead to the placement of merchant plants near gas supply sources, the development of gas clean-up technology at the wellhead, and development of inexpensive gas-to-liquid technologies.

Expansion of gas supply will require the development of new sources and technologies to enhance production of mature fields. Access to deep water supplies in the Gulf and to the Rocky Mountain Basins will be needed. Low-cost exploration and production technologies will be critical for natural gas supply expansion.

Technology

Technology is becoming more critical to the success of the gas industry, yet few are willing to make the necessary R&D investments to ensure continued advancements. Changing business conditions are causing companies to cut back on R&D investment except where it will translate quickly into direct profitability.

- *Two R&D directions: efficiency-based and new service-based.* New research investments by gas companies will fall into two basic categories: investments that will improve cost efficiency and investments that will result in new value-added services for customers.

- *Applied engineering favored over basic research.* Future R&D investments will focus on engineering of existing or emerging technologies, while investments for long-term, basic R&D will largely disappear.

- *New gas technologies will come from exploiting cutting-edge technologies from other industries.* Gas companies will capitalize on technology advancements and innovations from outside the gas industry.

Information technology will become more critical to the success of the gas industry. The integration of information and data and the automation of pricing and billing procedures will determine the pace of transformation of gas to a competitive industry. The willingness of consumers to accept these new technologies will also be a contributing factor.

Distributed generation technologies will help the energy industry. Distributed generation will reduce the need for new transmission lines, allow energy systems to function better over time, and create new end uses for gas.

Policy

New long-term policies are needed to stabilize business strategies. The government should develop policies and regulations that outline its long-term objectives. This will help to create a stable environment that will encourage gas companies to develop effective business strategies and make longer-term technology investments.

- *Kyoto could result in piecemeal policies.* While it is unlikely that the Kyoto Protocol will be adopted and met within the United States, continued pressure to develop climate change strategies will shape gas use. Government must avoid using a piecemeal approach to developing climate change policies.

Greater flexibility is required in policies and regulations. Some of the current regulations reflect concepts about technology that are over 30 years old. New policies must be flexible enough to allow for future technology changes and energy systems.

- ***New policies must focus on financial incentives for all parts of the gas supply/delivery/use chain.*** Any new government policies must provide market-based incentives that take into account the interactions among all parts of the gas value chain.

Current policies limit new supply development. U.S. producers are currently locked out of all offshore supply areas of the United States except for the Gulf. Policies and regulations must be modified to allow for new gas production.

Government must step in to bolster public benefit R&D. The shift in technology focus within the gas industry will require the government to provide additional support for valuable long-term gas technologies that have the potential to reduce environmental impacts, secure future supplies, improve safety, and lower energy costs on a national scale.

3 Major Technology Objectives

The changes occurring in energy markets create new technology objectives for the gas industry. While these objectives are organized within traditional segments of the natural gas industry, they will likely be addressed through new research strategies and will be financed through new mechanisms involving new players.

Natural Gas Technology Objectives

Exploration and Production

- Cheaper ways to produce gas from conventional sources
- New, low-cost methods of producing gas from new sources (e.g., methane hydrates)

Transmission

- Life extension of existing pipelines at a cost that is lower than new construction
- New, low-cost construction methods and materials
- Improved reliability and system integrity
- Technology for resource sharing and load leveling (e.g., storage and smart technology)

Power Systems

- Environmentally benign methods of power generation (e.g., zero emission combustion and gas co-firing of coal)
- Carbon separation and sequestration technology
- Interconnection of distributed generation technologies with the power grid

End-Use

- Inexpensive, reliable distributed generation technology
- Safety improvement and cost reduction
- New uses for gas (e.g., gas air conditioning)

Technology Focus Areas

These major objectives correspond to three key technology focus areas:

Natural Gas Supply Technologies – including exploration, extraction, processing, conversion, pipelines, storage, and infrastructure issues.

Power Systems Technologies – including central station power generation, non-utility power generation, distributed power systems, and environmental controls.

Technologies for Emerging Markets – including enabling technologies that support new markets and uses for gas and technology that address system issues such as smart energy management, delivery and storage infrastructure, environmentally friendly technology, and small and large end-use applications.

While each area addresses a particular set of technology challenges and solutions, they are inextricably linked. For example, pipeline infrastructure technology needs derive from changing power system requirements and shifting end user demand as well as by requirements associated with the supply chain. Similarly, trends in distributed generation affect all segments of the natural gas industry, not just power systems. Therefore, some of the technology challenges and R&D priorities presented in the following chapters are discussed in more than one area, but each reflects a unique technology perspective.

4 Natural Gas Supply Technologies

The ability of the natural gas industry to meet the large increases in demand expected in the next 20 years could be severely compromised by limitations of the supply infrastructure. New production from both conventional and new sources will be needed at prices that meet consumers' expectations and encourage producer investment. Aging pipelines and delivery systems must be improved, and new, low-cost construction methods are needed to handle expanded demand. Market restructuring may also create supply and demand imbalances that will require additional gas storage capacity and distribution strategies. These challenges require new technologies and create new priorities for gas supply research and development. Challenges and R&D responses for gas supply and delivery can be classified into six categories.

- Exploration
- Extraction
- Processing
- Pipelines
- Storage
- Systems Issues

Exhibit 1 presents an overview of technology objectives, challenges, and R&D responses for natural gas supply. These challenges and R&D priorities are summarized below.

Exploration

Technology Challenge: Resources are difficult to characterize without exploratory drilling.

Finding and characterizing new plays without drilling is difficult due to the lack of geological and geophysical reservoir data caused by the limited capability to generate data about the quality, quantity, and location of new plays. Seismic technology should be improved to image the extent of gas resources and natural fracture systems, which are typically the producing mechanisms for gas at depths below 12,000 feet. Such a capability would minimize and optimize exploratory drilling, and thereby reduce exploratory/characterization cost.

R&D Priorities

Improve tool technology to enhance seismic resolution. This technology is of particular importance for deep, high-pressure and high-temperature reservoirs. Down-hole residence times in these environments are very short, which limits the level of accuracy of current tools. In order to improve characterization in these harsh environments, new seismic tools must be developed with better down-hole characterization accuracy and/or greater operating limits to allow increased seismic resolution in short down-hole residence times.

Improve velocity models and interpretation methods for complex reservoirs. Specific technologies to be explored include 3-D and 4-D seismic in multicomponent and/or cross-well situations.

Improve remote sensing methods. Such technologies are necessary to improve identification of regional prospects in basin-centered gas formations.

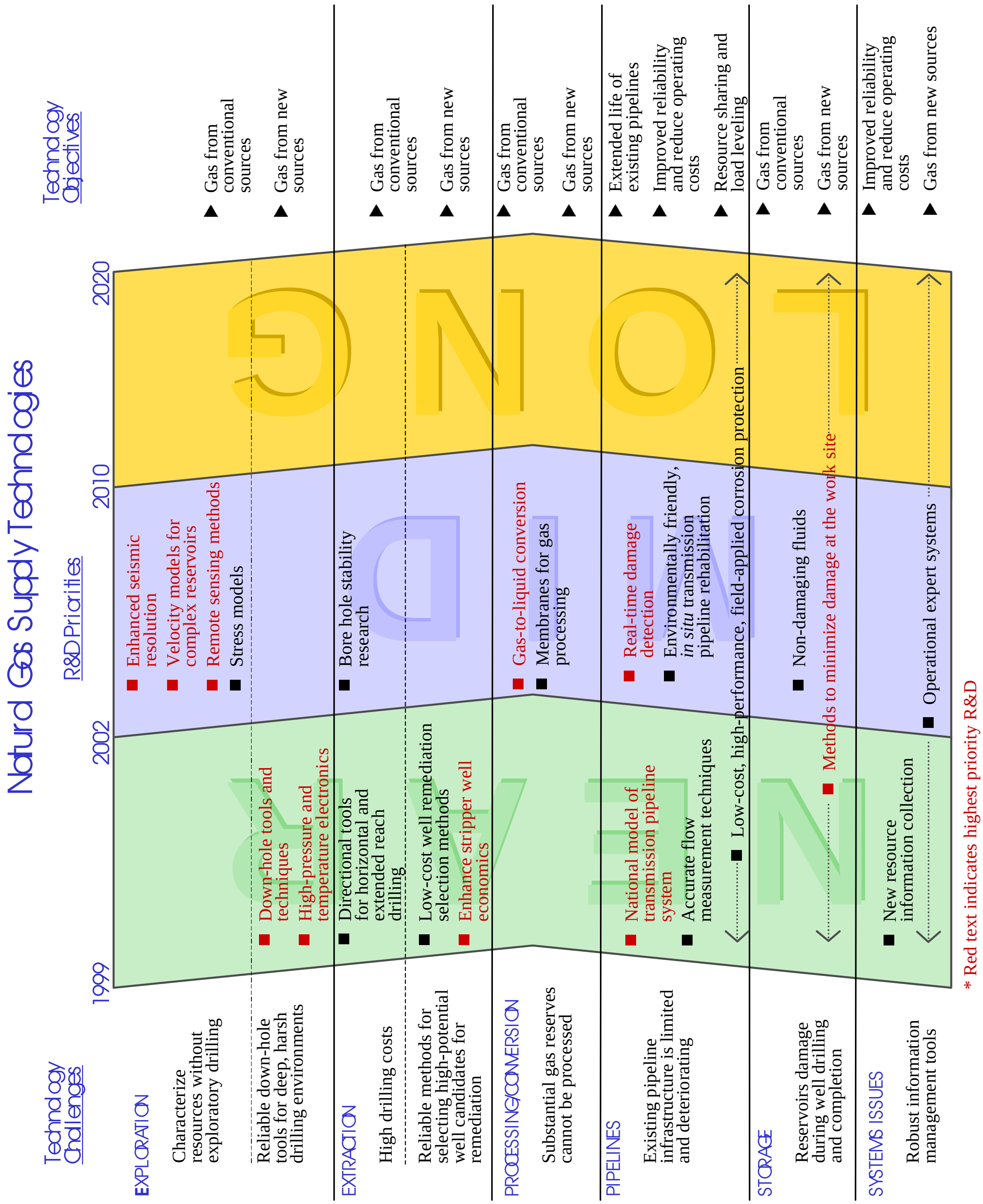

Exhibit 1. Natural Gas Supply Technologies

Develop stress models and improve rock mechanics to identify systems of natural fractures. Better exploitation of natural fracture systems will yield better geophysical data and reduce the need for costly drilling in some resource characterization.

Technology Challenge: Down-hole tools are not reliable in deeper, harsher drilling environments.

The capital investment for down-hole tools is large, not only for initial acquisition but also for replacements due to loss or improved technology. In addition to costs, current tools have reliability issues. Extreme down-hole environments (high temperature, high pressure) frequently compromise the reliability of equipment and sensors, and data transmission rates are too slow to reliably sense and control tools in real time. Furthermore, down-hole tool problems are often perpetuated because many companies continue to use outdated or inefficient technology rather than risk investing in advanced but more expensive tools due to the potential for loss.

R&D Priorities

Improve down-hole tools and techniques. Novel drilling techniques and casing methods are needed to counteract high drilling and casing costs. The overall methods of drilling and reinforcing wells should be reconsidered on a systems basis when developing these novel techniques. Research should include "smart" down-hole tools that incorporate various sensors so that steerable drilling systems can be employed.

Develop improved high-pressure and high-temperature electronics. Current research efforts are aimed at developing higher-temperature (>350°F) and higher-pressure (>10,000 psi) electronics technology. Alternative approaches, such as shielding of existing electronics to increase their robustness in harsh environments, should also be investigated. Additionally, the reliability of sensors obtained from electronics vendors tends to be inconsistent. An independent laboratory test to rate these electronics may help judge them according to an industry-accepted standard.

Extraction

Technology Challenge: Drilling costs are a significant portion of E&P costs.

Many factors contribute to drilling costs. Although drilling costs are generally low, they represent a significant development cost in light of current low margins for natural gas. In addition to relatively high tool costs, the overall approach used to drill horizontally can be costly and cost to case the well bore are high. The difficult nature of the drilling environment in certain reservoirs (e.g., hard rock, hard/soft interbeds, deep reservoirs) can drive the costs even higher.

R&D Priorities

Improve directional tools and methods in horizontal drilling. Sensors are needed that can "see ahead" of drilling, especially for horizontal drilling. Sensors would allow more strategic placement of wells in reservoirs to enhance the recovery process. Improved technology can make the drilling process more cost-effective and decrease the amount of lost or bypassed gas.

Conduct extensive bore hole stability research. Research that broadens the understanding of bore hole characteristics (e.g., irregular bore hole diameters, cave-ins and wash-outs, drilling in unconsolidated sands and shallow water flow environments) in extreme environments, particularly deep water, can help decrease drilling and operational costs.

Technology Challenge: Reliable methods for selecting high-potential well candidates for remediation do not exist.

It is difficult to know which wells are good candidates for remediation without adequate evaluation tools and techniques.

R&D Priorities

<u>Develop low-cost well remediation selection methods</u>. New methods should be developed and specifically geared to independent reservoir operators who may not have adequate resources to independently develop such remediation methods.

<u>Enhance stripper well economics</u>. New strategies, such as using on-site power to improve power and cost efficiency are needed to improve the economics of low-flow rate wells and facilitate more widespread remediation.

Processing and Conversion

Technology Challenge: Substantial gas reserves exist that cannot be economically produced.

Significant U.S. gas resources exist but are uneconomical to produce because they have high impurities or are sufficiently far from pipeline access.

R&D Priorities

<u>Develop new methods for gas-to-liquid conversion</u>. New approaches to gas-to-liquid conversion can reduce the overall quantity of "stranded gas."

<u>Increase membrane use in gas processing</u>. Membranes have the potential to reduce the footprint of gas processing operations and decrease disposal and capital costs.

Pipelines

Technology Challenge: The existing pipeline infrastructure is limited and deteriorating, while rehabilitation and expansion are very costly.

There is increasing concern about restricted deliverability of the pipeline system and the high costs associated with system expansion, maintenance, and rehabilitation.

R&D Priorities

<u>Develop techniques for low-cost, environmentally friendly, in situ transmission pipeline rehabilitation</u>. Advanced technologies that reduce the costs of expanding, maintaining, and repairing pipelines would enable the industry to more rapidly respond to market gas demand. Developing *in*

situ solutions for damage and repairs that do avoid large-scale excavation will reduce maintenance costs.

Establish real-time, third-party damage detection procedures. More immediate response to pipeline damage will reduce significant deterioration and enhance safety (e.g., damaged sections can be shut down in real time).

Create a national model of the North American transmission pipeline system. Although several different models already exist, they should be re-evaluated and combined with new data to create a comprehensive pipeline model that can help address deliverability restrictions and transmission issues. A national model will allow the industry to respond more effectively to anticipated rises in demand and ensure long-term system reliability. The model could also be used to assess future storage requirements.

Develop more accurate, less expensive operational flow measurement techniques. Cost-effective flow rate measurement can enhance deliverability.

Develop low-cost, high-performance, field-applied corrosion protection. New methods and/or materials can reduce corrosive deterioration and maintenance costs while prolonging pipeline longevity.

Storage

Technology Challenge: Reservoirs incur damage during well drilling and completion.

The lack of understanding of the circumstances and conditions surrounding reservoir damage contributes to decreased productivity due to lost product, repairs, and other associated costs.

R&D Priorities

Develop non-damaging fluids. Fluids for drilling and fracture stimulation can cause damage to reservoirs. Novel non-damaging fluids or alternative methods of accomplishing the same end result would decrease costs while increasing productivity.

Minimize damage at the working site. Reservoir damage caused by drilling, perforating, and pumping fluids and methods for controlling such damage should be specifically explored.

Systems Issues

Technology Challenge: There is a lack of robust information management tools.

There is a critical need for real-time, cross-cutting monitoring and reporting technologies. In addition, newly developed information technology, such as the Internet, are under utilized and would help connect overall systems and maximize productivity and efficiency.

R&D Priorities

Enhance new resource data and information collection and dissemination. More complete information about new gas resources should be collected and made more widely available throughout the industry. This information should include initial economic data to evaluate the economic feasibility of extraction.

Develop operational expert systems. To address the ongoing loss of expertise and knowledge facing the industry due to workforce adjustments, expert systems for all operations, from exploration through processing, should be developed. These systems will ensure that valuable expertise and knowledge are not lost, and ease the ongoing transformation occurring within the industry as a result of market forces and deregulation.

Public Sector R&D Priorities

Exhibit 2 outlines some of the most important priorities for public sector investment in natural gas supply R&D. These areas, selected by industry representatives, are deemed critical for public investment if the industry is to meet its technology objectives. In all cases, collaborative efforts involving public-private partnerships will be needed in these areas to overcome important technology challenges. Although industry has identified additional R&D areas requiring public sector investment, the priorities in Exhibit 2 are considered to be among the most important.

Exhibit 2. Gas Supply: Public Sector R&D Priorities

Top Public R&D Priorities	Why Should Government Be Involved?	What Should Government Do in This Area?	What Are the Consequences of No Government Involvement?
National model for transmission pipeline system	– The model, although necessary, is not driven by market demand – Such a model could have cross-cutting application – Individual companies understand their own systems but not those of others – No standards or universally accepted models currently exist – Confidential information from competing companies will be required – Industry cannot supply the level of expertise needed for such a project – The model will require extensive ongoing maintenance and updating	– Fund the work needed to create this model (although a private capability to perform this work exists, it needs funding) – Assemble a group to determine what actually exists and what needs to be developed	– There will be less opportunity for distributed generation – Markets may be limited without the model – The model will not be created
Technologies that see ahead of the drill for horizontal wells	– The technology is not driven by market demand – Research requires too long-term an investment for industry – High development costs will be defrayed – No technology exists that is the clear path to pursue for examining noise source – This is fundamental, precompetitive research – Individual companies do not have the staff or R&D money to develop these technologies	– Fund precompetitive research – Make the results part of the public domain, and the market will disseminate the technologies – Government participation can bring together all the pieces of this multifaceted problem	– In today's market, the technology will not be developed – Chances increase for bypassed gas – Less gas will be located during exploration – Development costs will remain high
Novel drilling and casing methods	– Revolutionary changes in the technology rather than evolutionary changes are needed – Technology involves fundamental research – Existing technologies need to be demonstrated and government is well-suited to assist	– Fund more fundamental, pre-competitive research – Conduct field demonstrations – Make the results part of the public domain	– The long-term seeds for future development will not be planted – Although the work will be done, it will progress slowly – Only incremental, evolutionary improvements will be considered – Natural gas will lose market share due to high costs
Improved technology to see down-hole, seismic resolution	– Conduct basic research for new approaches – Nonpatentable information will be developed – The return on investment is not large enough for industry to support high development costs – Some sources of the techniques/technology required are outside of the industry; government would have more access to them	– Fund fundamental research – Conduct demonstrations of technologies – Technology may require super computers - national labs may meet the need	– Higher dry hole rates – Deep gas will not be developed – There will be increased occurrence of bypassed reserves

5 Power Systems Technologies

Natural gas currently accounts for only 14 percent of the nation's electricity generation, but about 50 percent of non-utility electricity generation. The deregulation of the natural gas and electric industries should create substantial opportunities for increased power generation from natural gas, whether the system used is a gas turbine, fuel cell, engine, microturbine, or other technology. Indeed, the Energy Information Administration projects that natural gas use in power generation will roughly triple from current levels by the year 2020.

However, there are also a number of technology barriers that limit expanded use of natural gas in power systems, particularly in distributed power applications where a number of institutional barriers also must be overcome. Opportunities for competing power technologies may vary based on local conditions such as gas availability, electric transmission and distribution capacity, and regulations, among others. The challenges and the research and development (R&D) responses to address them can be classified into four categories, which are depicted in the table below along with their relevance by type of application.

Relative Importance of Technology Challenges to Power Systems

Challenges	Distributed Power (0 - 50 MW)	Intermediate Load (30 - 200 MW)	Central Power Systems (> 200 MW)
Power System Economics	High	High	High
Connectivity, Communications, and Control	High	Low	Low
Emissions Control and Monitoring	High	Medium	Medium
Demonstration and Testing	Medium	High	High

Exhibit 3 presents an overview of technology objectives, challenges, and R&D responses for power systems technologies. These challenges and R&D priorities are summarized below.

Power Systems Economics

Technology Challenge: Capital costs of natural gas burner systems are too high, particularly for distributed power technologies, to compete effectively with other electric power generation technologies.

The manufacturing cost per generating unit is currently very high for distributed power technologies, contributing to limited market size and penetration. To reach desired operating efficiencies, the capital cost may be high due to high cost of component fabrication, high cost of materials, or high cost of assembly due to low production volumes. Besides direct manufacturing costs, capital costs for installation, control systems for grid connectivity and communication, and emissions control, and the associated warranty and product liability costs can be significant and must be factored into the total system's cost. The overall capital cost and the specific capital cost per unit of electricity must be affordable to the user. This is particularly important as equipment is scaled down to smaller sizes, perhaps even for residential users.

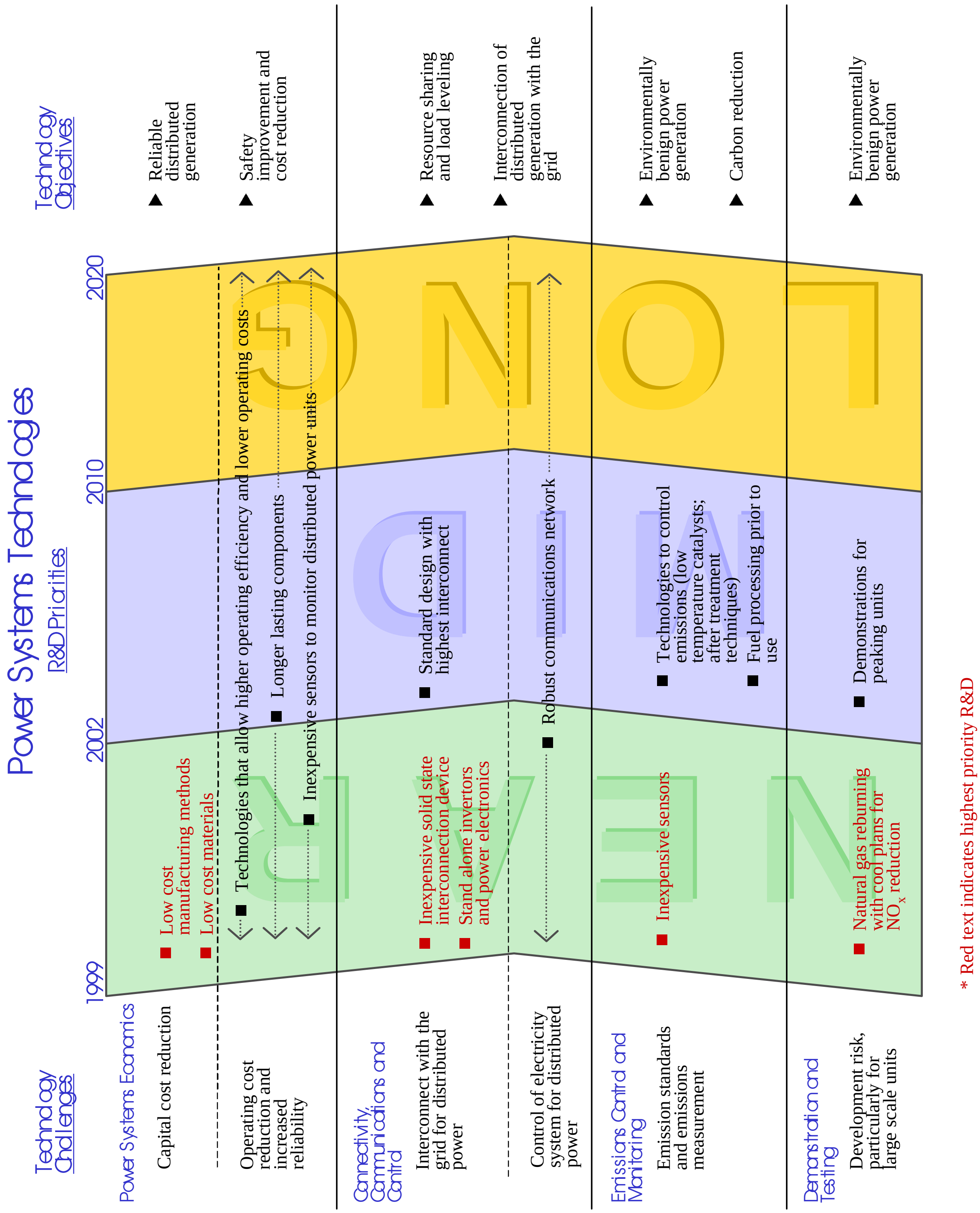

Exhibit 3. Power Systems Technologies

R&D Priorities

Develop lower cost manufacturing methods. Applied research is needed to develop manufacturing methods that produce power system equipment components and systems at a much lower cost, and may include new processes or improvement of existing processes. An area where lower costs are needed includes the material components of fuel cells.

Develop lower cost materials. Research is needed to develop low cost materials that improve system efficiency and performance, and may include basic materials research.

Technology challenge: Operating costs need to be further reduced and reliability increased, particularly for distributed power technologies, to compete effectively with other electric power generation technologies.

The ability to deliver electricity economically from distributed power units will require higher efficiency levels than currently available, especially for small units (< 5 MW). In small distributed power units, efficiency is also hindered by the lack of good recuperators for low grade waste heat. Pressure swings in natural gas supply also limit efficiency, since the system needs to be designed for these swings. Power quality issues, such as harmonic distortion in microturbines, may also reduce efficiency. Other efficiency-limiting characteristics include turndown ability and size limitations of equipment, particularly for engines.

The need to check and/or replace unit components also contributes to higher operating costs, as maintenance visits increase costs substantially. In addition, user reluctance to adopt distributed power units may be caused by uncertainties regarding reliability, whether it relates to materials, components, control systems, or remote sensors.

R&D Priority

Develop technologies that allow higher operating efficiency and lower operating costs. Research is needed to improve the practical chemistry in fuel cells for increased efficiency and reduced reforming costs. Research may also address avenues to overcome thermodynamic limitations in turbines, or improve waste heat recovery for fuel cells. Octane additives may be developed to allow increased efficiency in engines.

Develop longer lasting components. Research is needed to extend the lifetime of wear components, in addition to developing inexpensive, long lasting spark plugs for engines. A permanent lube oil system may also be investigated to reduce maintenance visits.

Develop inexpensive sensors to monitor distributed power units. Research may include developing spin-off sensor technologies developed for engines in natural gas-powered vehicles, and sensors for engine lube oil systems.

Connectivity, Communications, and Control

Technology Challenge: Lack of industry standard for interconnect with the grid for distributed power.

One of the biggest uncertainties in distributed power is how units will interface with the power grid and with other distributed power units. At different times, the user may receive power from the grid and provide power to the grid, and little data exists on the interaction of varying generators with each other on the line and going back to the substation. There is also uncertainty as to whether the interconnect device would be a part of the distributed power unit, and there is a lack of understanding regarding standard compared to function for interconnect devices.

R&D Priority

Develop standard design with highest interconnect. A standard design for interconnect devices will enable a set of parameters for mass production of such devices. This should allow states, utilities, and users to alleviate interconnect problems and avoid state by state or company by company differences.

Develop inexpensive solid state interconnection device. Devices will allow two way access for power so that it can be provided to the grid or taken from the grid. This may be very important for residential use in particular.

Develop stand alone invertors and power electronics. Stand alone invertors and power electronics can assist in deployment of distributed power by helping to alleviate power quality issues.

Technology Challenge: Improved communication and control of electricity system for distributed power are necessary.

As additional distributed power units are placed into service, managing the electricity grid will become more complex. There is currently no overriding control "philosophy" to ensure power requirements will be met for daily peak usage and to efficiently distribute loads. The grid "controller"must manage supply to meet demand with distributed power units, and will need to determine when it will be most cost-effective to run individual units. There is also a lack of real-time price signals. Together, these issues may lead to an evolution in the fundamental design of the distribution system.

R&D Priorities

Develop robust communications network. Investigate devices that supply information to enable more effective control of distributed power units connected to the electric grid. This may include the development of "smart" systems, which may also increase system reliability. A needs analysis for siting and distribution could also be performed.

Emissions Control and Monitoring

Technology Challenge: Inexpensive technology is needed to meet tightening emission standards and to measure emissions, particularly in non-attainment areas.

To improve air quality, emission standards have been tightened by the Environmental Protection Agency and state agencies. The current emission concern is NO_x, although other air toxics are also important. Generally speaking, emissions can be reduced, but at considerable cost to system efficiency and economics. In addition, emissions must be detected and measured inexpensively at the generation site, particularly for distributed power units to determine emissions and changes in operating conditions. The ability to capture, reprocess, and sequester CO_2 would be beneficial, but with current technologies, it may be neither economically nor technically feasible to accomplish this.

R&D Priority

Develop technologies to control emissions, including low-temperature catalysts and other after-treatment techniques. Investigate emission control systems that enable reduced emissions without compromising system efficiency significantly. Evaluate modifications of combustion technology developed by automakers for emission reductions.

Investigate fuel processing prior to use. This is potential method to reduce emissions in stringently regulated areas.

Develop inexpensive sensors. Examine inexpensive sensors that can provide data to control systems on emissions such as NO_x and other process variables to enable improved control of power generation units.

Demonstration and Testing

Technology Challenge: Demonstrations are necessary to reduce risk, particularly for large scale units.

The biggest barrier in advancing technology for large scale units is the cost associated with designing, developing, constructing, and testing systems that "push the envelope" to further increase system efficiency. Current limiting factors include inlet temperature, materials, existing sensors and control, and modeling. Large scale units with new technology are also likely to carry a high insurance cost, given the high cost of failure. Individual companies lack enough funding for development and demonstrations for both central power stations and peaking units that can be easily started up and shut down. Other knowledge gaps include capability for fuel flexibility and retrofitting existing facilities with natural gas.

R&D Priorities

Demonstrations for peaking units. Natural gas fired peaking systems may be an option to combined cycle cogeneration, and may replace coal fired peaking units as environmental regulations are further tightened.

Demonstrations of natural gas reburning with coal plants for NO_x reduction. Reburning offers an opportunity to significantly reduce emissions of coal plants, although operational results will depends on the boiler used. Operational experience may help improve models for reburning. Reburning may also help coal plants avoid the need to install additional emission control equipment.

Public Sector R&D Priorities

Exhibit 4 outlines some of the most important priorities for public sector investment in R&D on power systems technologies. These areas, selected by industry representatives, are deemed critical for public investment if the industry is to meet its technology objectives. In all cases, collaborative efforts involving public-private partnerships will be needed in these areas to overcome important technology challenges. Although industry has identified additional R&D areas requiring public sector investment, the priorities in Exhibit 4 are considered to be among the most important.

Exhibit 4. Power Systems: Public Sector R&D Priorities

Top Public R&D Priorities	Why Should Government Be Involved?	What Should Government Do in This Area?	What Are the Consequences of No Government Involvement?

Inexpensive, solid state interconnect device	– Government involvement is critical to success of the distributed generation concept
	– There currently are no interconnect standards, nor is there a large market demand
		– Develop universally accepted standards and guidelines
		– Provide funding for programs with broad applications (e.g., high-power electronics)
		– Ensure that size differences among devices (e.g., residential vs. commercial) will not cause additional problems/issues
		  – develop a “strawman” guidance document
		    – provides a national standard beginning point for interconnection
			– Acceptance of the new technology will be much slower
			– Development efforts will be less coordinated

Develop parameters for standard design (highest interconnect)			

Low cost materials and manufacturing methods	– The required development investment for industry alone is too expensive, long-term, and high-risk	– Conduct front-end material research
		– Provide seed funding for advanced manufacturing processes (consortia)
		  – companies involved in fuel cell development are small and have limited resources
		– Emphasize greater-benefit, “leap-frog” rather than incremental technology whenever possible
			– Acceptance of the new technology will be much slower
			– Fewer projects/products will end up in the market
			– Introduction of more efficient, less polluting technologies will be slower
			  – there is increased risk of brownouts, etc. if additional capacity is not added
			– Loss of intellectual technology transfer
			  – lack of government involvement will prevent information from being widely available

Develop low temperature catalysts for emissions control	– Government should work as a partner to help provide solutions to national environment problems	– Develop/fund consortia for catalyst development	– The technology will likely not be developed at all or will require an extensive development period – Limited ability to site new technology in certain markets – less market penetration

Develop inexpensive sensors for emissions monitoring	– Spread risks across a broad base of applications (operating parameters)	– Provide development funding to U.S. sensor developers/manufacturers
		  – increase domestic supply base
		– Assess national laboratory technology development and/or transfer
		  – disseminate existing data and technology
			– Technology transfer to manufacturers may not occur at all

6 Technologies for Emerging Markets

The deregulation and restructuring of gas and electric markets is causing widespread changes in the energy products and services offered to consumers. Pipeline companies, local distribution companies, electric utilities, non-utility generators, telecommunication companies, marketing firms, integrated energy companies, and other businesses are aggressively pursuing market niches that they project will be most profitable. As opportunities emerge in these market niches, new technology will be needed to satisfy customer expectations and to support the infrastructure required to meet new demands. Five areas define the scope of technologies needed to support opportunities in emerging markets.

- Smart Energy Management Systems
- Delivery and Storage Infrastructure
- Small-Scale Applications
- Environmentally Friendly Technology
- Large-Scale Applications

Smart Energy Management System

Technology Challenge: Real-time comparative measurement for consumption and pricing

To achieve economic efficiency in gas markets, information about demand, supply, and prices must be quickly available to allow consumers and suppliers to make optimum decisions. Up to now, real-time measurement of consumption and pricing have not been widely implemented among gas customers due to lack of proper equipment, appropriate information infrastructures, or adequate procedures and rules for sharing data.

R&D Priorities

Develop procedures and rules for establishing a market for real-time transactions. Mechanisms for real-time collecting, transmitting, and sharing of information about market prices and gas usage are emerging but are not well-established. Developing common procedures for exchanging market-based information will hasten stability and allow markets to achieve equilibrium without wide fluctuation in prices and supplies. Information sharing can be aided by using high data transfer rates enabled by Internet-2.

Develop low-cost equipment for measuring use and real-time pricing. New, low-cost equipment is needed to measure real-time gas use by residential, commercial, and industrial consumers and enable real-time pricing. Pricing by the day, hour, or minute is possible through integration with telecommunication systems and the Internet. Equipment options include retrofit of existing meters, new measurement devices (e.g., ultrasonic), and a combined electric/gas meter.

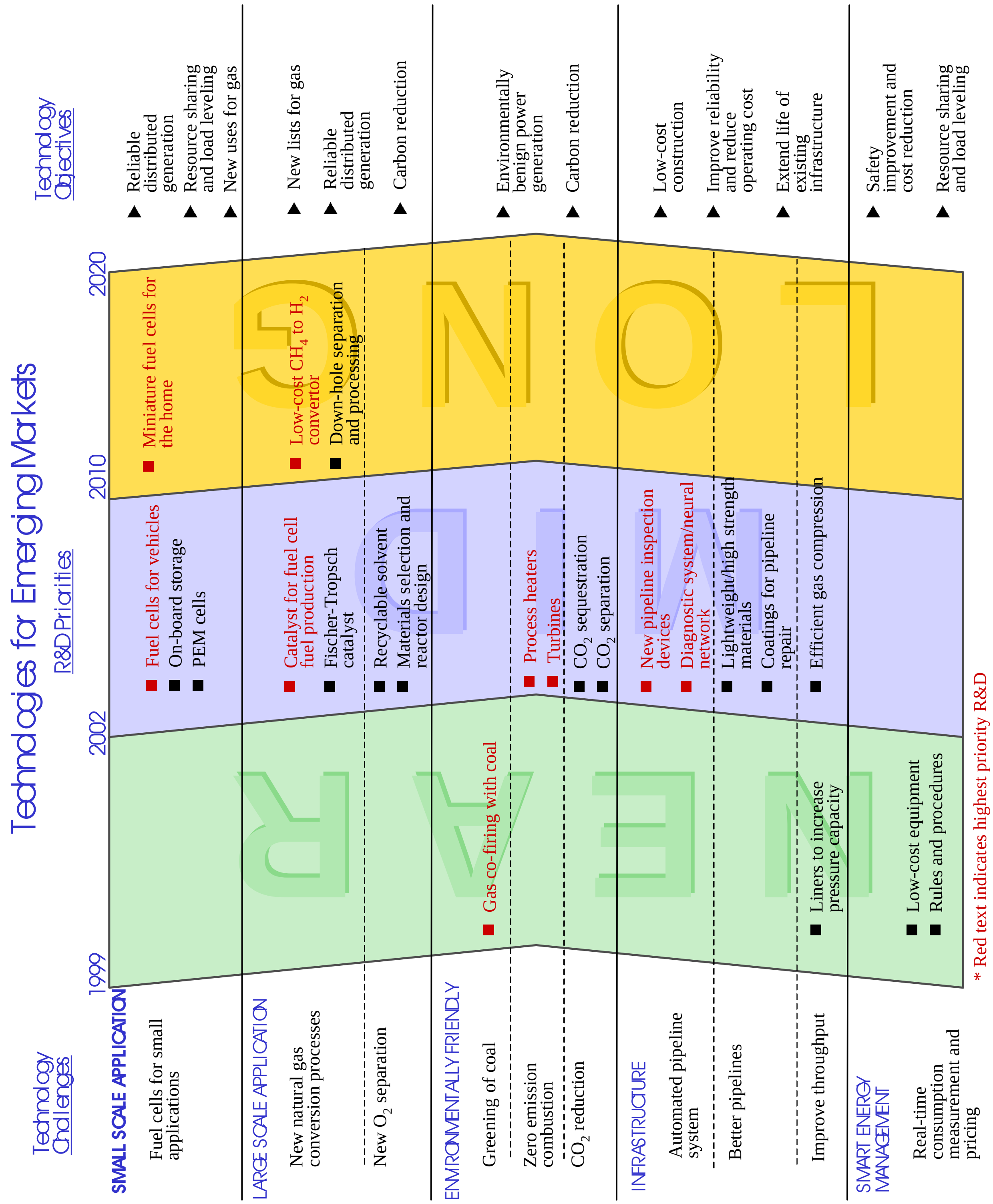

Exhibit 5. Technologies for Emerging Markets

Environmentally Friendly Technologies

Technology Challenge: Use natural gas to improve the environmental performance of coal-fired power plants.

Despite recent improvements, coal plants to continue to generate large amounts of air pollutants and CO_2 compared to gas-fired plants. However, if relatively small amounts of natural gas are burned in conjunction with the coal, substantial reductions in emissions can be achieved.

R&D Priorities

Implement natural gas injection for preheated coal burner systems. Burning about 5-10% natural gas in a pulverized coal boiler helps devolatilize the NO_x precursors in a reducing environment and causes them to break down very quickly before the main combustion. This will achieve about 70-80% NO_x reduction with as little as 5% natural gas injection.

Technology Challenge: Pursue zero emission combustion strategies.

Although natural gas is already the cleanest fossil fuel, opportunities exist to further improve the environmental performance of natural gas burning systems. New materials, equipment designs, and combustion control technologies are enabling natural gas-fired turbines and industrial equipment to burn much cleaner. New research can lead to advanced equipment that emits virtually no criteria air pollutants.

R&D Priorities

Develop zero emission combustion technologies for industrial equipment. Industrial furnaces and process heaters that emit no air pollutants would have large environmental benefits for industrial users and create new opportunities for the natural gas industry. However, additional research is needed on the design of burners and combustion chambers and on NO_x control in O_2-enriched combustion environments.

Develop zero emissions gas turbines. New high-temperature materials would allow higher thermal efficiencies in turbines and lower emissions per Btu input. Additional research is needed for feed control systems and redesign of combustion chambers. Oxygen-enriched combustion requires additional research on NO_x formation.

Technology Challenge: Reduce CO_2 emissions resulting from natural gas combustion.

Although most greenhouse gas reduction strategies will likely increase near-term demand for natural gas as an alternative to coal and oil, additional efforts are needed to reduce carbon emissions associated with natural gas use. One approach – converting methane to hydrogen with elemental carbon as a byproduct – will create a clean fuel from gas and is discussed later. However, economical post-combustion carbon removal has widespread appeal because it offers the potential to retrofit existing equipment. A key issue, however, will be how to achieve economical separation of CO_2 in distributed generation applications.

R&D Priorities

Develop CO_2 separation, capture, and sequestration technology. New methods are needed to separate CO_2 from exhaust gas streams and capture it for use or disposal. Separation technology is needed for both exhaust streams that contain oxygen and those that don't. The latter is quite costly but will be needed for distributed systems. While sequestration technology strategies will be needed for all types of fossil combustion, gas industry efforts should emphasize separation.

Delivery and Storage Infrastructure

Underlying the anticipated expansion of natural gas markets are serious concerns about the integrity, efficiency, and availability of the delivery and storage systems. Three basic strategies are needed to meet future system demands including maintaining the current system at the lowest cost, expanding the current system at the lowest cost, and increasing the throughput of the current system. Storage will be an integral part of a strategy to protect against supply imbalances and price spikes.

Technology Challenge: Develop automated, on-demand pipeline integrity systems.

Better methods are needed to monitor, protect, maintain, and repair existing pipelines to ensure the integrity of the gas delivery system. More automated, on-demand monitoring and diagnostic methods would enable early detection of problems, preventative maintenance, and quick repairs.

R&D Priorities

Develop advanced pipeline location and inspection devices. Alternatives are needed to conventional pigging for inspecting pipelines because some portions of the lines are not inspectable. Sensors are needed to better characterize damage in a facility to enable operators to make engineering decisions; currently, damage can be detected but it cannot be sufficiently characterized to take corrective action. A sensor/transmitter device should be developed that could be inserted in the line or attached to the line to communicate a problem and to let workers in the area know there is a gas line buried there. "Smart skins" would automatically detect when pipelines have been touched and communicate this information back to a central location.

Create a neural network diagnostic system to obtain and use information on infrastructure integrity. A complex distribution system not only requires equipment to detect the status of the pipeline system but also a sophisticated neural network to collect and analyze information. Some neural networks exist but they do not collect or process good data on gas usage or pipeline operational status. In addition, better dynamic modeling of the national energy system is needed – one that is integrated for both electric and gas – for incident analysis.

Technology Challenge: Tools and materials for better pipelines

New low-cost construction methods are essential for expanding natural gas service. Because new pipelines will become a part of the permanent delivery infrastructure, it is essential that they take advantage of the latest technology. However, competition may force companies to ignore any technology advances that add cost to new construction.

R&D Priorities

Develop lightweight, high strength materials for pipeline construction, including liners and inserts for maintenance. Liners and insertions improve pipeline integrity and extend life. Lighter weight materials that do not compromise strength are needed for new pipeline construction.

Develop better welding techniques and alternatives to welding. Welding methods for pipeline construction and repair need to be improved to lower costs, improve reliability and reduce failure rates.

Use advanced coatings and application techniques for pipeline repair. Better coatings will extend pipeline life and ensure the integrity of pipeline repairs, while lowering costs of pipeline maintenance.

Technology Challenge: Increase mechanical throughput for existing infrastructure

A third option for expanding natural gas delivery is to increase mechanical throughput in existing and new pipes. This will require new technologies and approaches that improve compression, increase pressure, and increase the Btu content of gas.

R&D Priorities

Increase efficiency of natural gas compression. Research is needed to improve compressor technology in order to increase energy efficiency of transmission. Also, microturbines could be employed to recover energy resulting from the pressure reduction that occurs when going from main pipelines to distribution systems.

Increase pressure capacity of pipelines. Research is needed to find new methods that will allow existing pipelines to handle higher pressures through the use of liners and other approaches. Advanced materials and joining research is needed to enable higher pressures in new pipelines.

Explore novel approaches to increasing throughput. Changing the characteristics of the gas media could increase throughput. For example, a fluid or additive in the gas could move the product with less pressure drop. Also, a higher Btu gas product could be moved through the line and then separated at the end user, requiring a device at the end user to bring the gas down to a lower Btu.

Small Scale Application

Technology Challenge: Fuel cells for small applications

Fuel cell technology for vehicles and homes represents a tremendous opportunity to expand natural gas demand without increasing environmental burdens. The cost of fuel cells continues to be too high for most applications and a number of technology barriers associated with the reformers and components of the PEM (proton exchange membrane) must be overcome.

R&D Priorities

Miniaturize fuel cell technology for commercial and residential use. Fuel cell technology must be designed for small applications to be made compatible with the power and energy demands of the commercial and residential users. One desirable feature is some sort of "energy flywheel" . There are two choices for following a load: either baseload the reformer and store the hydrogen so the fuel cell responds quickly, or baseload the reformer and the fuel cell and include an electrical storage option in the package. In either case the desire is to be able to store hydrogen or electricity cheaply for distributed generation for commercial and residential users.

Develop fuel cell systems for vehicles. Research is needed to develop technology and systems for fuel cells in vehicles. This includes a miniature reformer for natural gas, greater on-board storage, and peak power storage technologies. New materials will be needed to handle high-pressure, on-board storage.

Develop PEM fuel cell technology. Further research and development work is needed for this promising technology. Technology requirements include a membrane electrode assembly that costs about $40/kW, a CO-tolerant catalyst, and less expensive polymer membranes. Research on augmenting fuel cell performance with oxygen is also needed.

Technology Challenge: Natural gas cooling for the home

Gas-fired air conditioners are another large potential market for natural gas. Capital costs are currently too high for most consumers, even if life-cycle costs are favorable.

R&D Priorities

Low-cost desiccants and alternative cooling cycles. Lower-cost desiccant materials can offer a significant cost advantage for small home air conditioners. Longer-term research should focus on alternative cooling cycles that would eliminate the need for desiccant systems.

Large-Scale Applications

Technology Challenge: New oxygen separation technology

New, low-cost methods of producing oxygen are critical to the overall economics of natural gas combustion systems. Oxygen firing virtually eliminates air pollutants by preventing the formation of NO_x during combustion and reduces the cost of collecting concentrated CO_2 streams for possible sequestration.

R&D Priorities

Research recyclable solvents and membrane technology. Research is needed on ion transfer membranes as well as conventional membranes. A recyclable solvent is needed that operates at ambient temperatures and low pressure.

Technology Challenge: New natural gas conversion processes: the "gas refinery"

The great promise of natural gas in transportation markets is in producing liquid fuels that can be integrated with the existing fleet and fueling infrastructure. Technologies are needed to enable use of Fischer-Tropsch (where CO and H_2 are converted into liquid hydrocarbons) and other reactions to convert natural gas to valuable products for transportation and chemical uses. While Fischer-Tropsch technology has been around since the 1920s, it is not competitive with lower-cost processes based on petroleum feedstocks. Opportunities also exist to increase the use of natural gas as a fuel gas for fuel cells. Fuel cells convert fuel gas and air electrochemically into power and are virtually emissions free (no combustion) and very efficient (40-70%). Technologies to capture these opportunities exist today, but are not economical or competitive with traditional power generation, particularly on a large scale.

R&D Priorities

Develop new natural gas conversion processes. Research is needed to develop catalysts, reactors, and processes to convert methane to high volume commodity chemicals. Efforts should include design of new Fischer-Tropsch reactors and advanced Fischer-Tropsch catalysts suitable for large-scale gas refining operations. A high priority is the development of low cost methane-to-hydrogen convertors that prevent carbon from taking a gaseous form. This would produce a clean fuel gas for fuel cells and elemental carbon as a byproduct (rather than CO/CO_2). New materials of construction may also be needed for reactors that handle high pressure gas processing.

Develop catalysts for production of the fuel-of-choice for fuel cells. New catalysts are needed that will selectively yield the gaseous fuels required for high efficiency fuel cells (those rich in hydrogen). Technologies are also needed for economical separation of hydrogen from fuel gases, particularly for those fuel cells that can tolerate only limited amounts of carbon monoxide (e.g., phosphoric acid fuel cells).

Public Sector R&D Priorities

Exhibit 6 outlines some of the most important priorities for public sector investment in R&D for technologies in emerging markets. These areas, selected by industry representatives, are deemed critical for public investment if the industry is to meet its technology objectives. In all cases, collaborative efforts involving public-private partnerships will be needed in these areas to overcome important technology challenges. Although industry has identified additional R&D areas requiring public sector investment, the priorities in Exhibit 6 are considered to be among the most important.

Exhibit 6. Emerging Markets: Public Sector R&D Priorities

Top Public R&D Priorities	Why Should Government Be Involved?	What Should Government Do in This Area?	What Are the Consequences of No Government Involvement?
Preheated coal systems using natural gas injection	– A small government investment will yield a large impact for industry – There is only a small window of opportunity in which to introduce the technology into coal plants – quick response is critical – This technology will provide large environmental benefits – The technology needs to be demonstrated quickly	– Fund demonstrations	– Power plants will focus on NO_x removal which will increase cost and create a secondary waste stream
Fuel cells for the home	– Too high-risk for individual companies – Industry has already invested 20 years in development – The technology offers a potentially large payoff – Support from the government will help reduce development costs – Government involvement will mitigate risk	– Fill in key technology gaps – Develop low-cost membrane technology – Develop inexpensive, safe, small-scale energy storage technology for the home	– The time to commercialization will be greatly increased – cost of membrane technology will be prohibitively high
Low cost CH_4 to H_2 convertor	– Development investment is too long term for industry – The technology is high-risk – This technology also supports fuel cell development	– Fund/conduct research for the underlying technology – fundamental chemistry and catalysis work	– The technology will likely not be developed at all or will require a very extensive development period
Diagnostic system and neural network to capture and use information **New inspection devices for pipelines**	– FERC research and development money will soon disappear – There is no incentive for private research and development	– Develop the underlying technology	– Safety problems/issues will increase – Environmental issues will not be addressed – The integrity of the infrastructure will be weakened
CO_2 separation technology	– Key drivers are public needs not market or customer needs – Climate change improvements results in public benefits	– Establish CRADAs to leverage investments – Overcome the physical/chemical hurdles in the flue gas separation process	– Costs will remain very high – Significant implications to U.S. economy if a Climate Change Policy is implemented

Appendix A: Meeting Participants

Matching Natural Gas Supply and Utilization for the 21st Century
A Senior Executive Colloquium
Houston, TX
January 21, 1999

Robert Armstrong
Senior Advisor Corporate Affairs
Burlington Resources

Rita A. Bajura
Director
Federal Energy Technology Center

Stanley S. Borys
Senior Vice President
Institute of Gas Technology

Michael Canes
Vice President
American Petroleum Institute

Charles Fritts
Managing Director of Government Relations
American Gas Association

A. Dean Fuller
Vice President of Fuels
Central and South West Corporation

Manoj K. Guha
Director of Special Projects and Technology Assessment
American Electric Power

Rita Hartfield
Manager, Competitive Analysis
Enron Corporation

Theopolis Holman
Vice President Transmission for Northeast Pipelines
Duke Energy

Paul Holtberg
Group Manager, Baseline Center
Gas Research Institute

Donald Mason
Commissioner
Public Utilities Commission of Ohio

Sarah McKinley
Executive Director
Distributed Power Coalition of America

Warren Mitchell
Chairman and President
Southern California Gas Company

Susan B. Ortenstone
Vice President
El Paso Gas Services Company

Alvin Pak
Director of Corporate Development
EPRI

Sandra Waisley
Acting Deputy Assistant Secretary for Natural Gas and Petroleum Technology

DOE Fossil Energy Gas Program Outlook Workshop
Houston, TX
February 24-25, 1999

John H. Anderson
Anderson & Associates Consulting

Kenneth L. Beckman
International Gas Consulting, Inc.

Stanley Borys
Institute of Gas Technology

Kevin Brady
Sperry-Sun

Randy Brown
Southern California Gas Company

Philip S. Cali
Nicor Gas

Gary Collins
Marathon Oil Company

William D. Diggs
Williams Technologies

Anthony J. DiGiovanni
Boston Gas Company

Jay Evans
International Gas Consulting, Inc.

Fred E. Followill
Lawrence Livermore National Laboratory

Steve Fortune
BP Amoco

William F. Fraizer
Chevron Petroleum Technology Company

Steve W. Gauthier
Institute of Gas Technology

Daniel E. Kincaid
Gas Research Institute

Fredrick G. Kolb
Columbia Natural Resources

Vello A. Kuuskraa
Advanced Resources International, Inc.

Alan Lamont
Lawrence Livermore National Laboratory

John D. Leeper
Edison Technology Solutions

Chris Lotz
Central and South West Services, Inc.

William J. MacDonald
Maurer Engineering, Inc.

Kent Perry
Gas Research Institute

David S. Pixon
Novatek

Jeremy Platt
EPRI

Bernard Saffell
Pacific Northwest National Laboratory

Dennis J. Seeley
National Fuel Gas Company

Robert Sam Shepard
BP Amoco Global Power

Eric E. Thomas
Southern National Gas Company

Michael R. Thompson
Pacific Northwest National Laboratory

Shannon Vinyard
Vinyard Technology Company

Steven E. Winberg
Consolidated Natural Gas Company

John C. Wolfmeyer

Duke Energy Corporation